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COMPARATIVE STUDY OF WHEEL LOAD STRESS AND WARPING STRESS ON CONCRETE PAVEMENTS

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ABSTRACT

The stresses in rigid concrete slabs result from wheel load and from slab movement induced by moisture loss and temperature changes across the depth of the slab. This paper presents comparative study of thickness design of concrete pavements considering the action of wheel loads and linear temperature distribution by using westergaard method. Warping stress caused by difference in moisture content between the top and bottom of the slab. The stresses arising from temperature difference are equal in importance those caused by heaviest loads. An important conclusion of this study is that warping stress responses were more significant than wheel-load stress.

KEYWORDS: Concrete Pavement, Temperature, Wheel Load Stress, Warping Stress

INTRODUCTION

Warping stress and wheel load stress are the stresses occur in rigid pavements. The Westergaard's developed closed-form stress solutions for calculating wheel load stress and warping stress for jointed concrete pavement. However, the actual pavement conditions are often different from Westergaard's ideal assumptions of infinite or semi-infinite slab size and full contact between the slab-sub grade interfaces. The Variation in temperature causes warping stress in concrete. Greater moisture at the top of slab results in downward warping and upward warping. Consequently, tensile stresses are developed in the slab. For wheel load the concrete pavement resting on a dense liquid is considered. Hence both the stress are evaluated simultaneously. In this paper we calculate and compare the stresses on concrete pavement and the temperature change was assumed to be linear.

BACKGROUND OF WARPING AND WHEEL LOAD STRESS

The factors that affects the pavement design are traffic loads and temperature variations. The concrete pavement performance depend upon level of stress and deflection in concrete slab but the stress considered to be most critical and this phenomenon should be studied & dealt with for better design. For this, the concrete pavements is categorized into two groups first the theory related to warping stress and second the stress due to wheel load.

WARPING STRESS

Warping of the pavement slab is caused by a difference in temperature between top and bottom of the slab. At day time the pavement slab gets heated under sunlight which tensile upwards while the bottom of the slab remains colder where compress stress develops.

The difference in temperature between the top and bottom of the slab depends mainly on the slab thickness and climatic conditions which causes slab to warp and the warping is restrained by the self weight of the slab. At night time the

bottom of the slabs get heated up due to heat transfer from the top when temperature falls the top of the slab becomes colder resulting in warping of the slab in the reverse direction in different regions of the slab.

WHEEL LOAD STRESS

Stresses due to traffic loads are present in the interaction between the wheel of a vehicle and the road surface .Wheel loads on concrete pavements cause tensile stresses to develop at the bottom of the slab. Because concrete is inherently weak in tension. The pressure from the wheel develops stresses in the different material layers in the road structure which develops the stresses in the concrete slab, and the strains in the sub base.

The bending of a slab due to traffic load develops stress on the pavement and it can be calculated by using westergaard equation. For analysis purpose, three different regions are recognised in a pavement slab—corner, edge and interior—which react differently from one another to the effect of temperature differentials, as well as load application. The concrete pavements undergo a daily cyclic change of temperature differentials, the top being hotter than the bottom during day, and cooler during night (IRC1988-58).

LITERATURE SURVEY

From the previous study showed that magnitude of vehicular loads together with environmental effects have a significant effect on induce tensile stresses within concrete pavements (yu.et al.1998 and hiller and roesler2002.)**.**Temperature distribution through the pavement's thickness is highly nonlinear, and that measured "stresses arising from restrained temperature warping are equal in importance to those produced by the heaviest legal wheel loads" (Teller and Sutherland 1935). The maximum differential was found to result in a substantially higher slab thickness than that designed with an effective temperature differential **(**Chen-Ming Kuol 1998**).**During the daytime fatigue damage is higher because of higher stresses caused by combined action of wheel load and warping stress which occur simultaneously (Kumar, shrinivas, Suresh, pandey).warping stresses could be high enough to result in cracking of the slab. To overcome this problem, the overlay slab must be made quite thick or, based on experience, the thin concrete overlay should be fully bonded to the existing pavement (Yoder & Witzak 1975).

WESTERGAARD’S CLOSED-FORM FORMULAE

To study the pavement slab, Westergaard has presented closed-form formulae for wheel load based on the assumptions of an infinite slab over a dense liquid foundation.

TRAFFIC LOAD

For illustrative purpose assume the slab as an elastic plate resting on dense liquid foundation. Westergaard theory has been used to calculate wheel load stress in concrete pavements .When a load is applied on the surface of a concrete slab, it will cause flexure of the slab thus producing tensile and compressive stresses (Setyawana, Zoorobb &Hasan2013). The Westergaard derive the formulae but later modified by teller and Sutherland to calculate the critical tensile stresses for each of these positions of loading are as follows:

The corner loading stress (c) modified by kelley is expressed in equation 1.

$$\sigma_c = \frac{3P}{h^2}\left[1 - \left(\frac{a_1\sqrt{2}}{l}\right)^{1.2}\right] \quad (1)$$

The stress in the critical edge region derived by Westergaard and modified by Teller and Sutherland shown in equation 2.

$$\sigma_e = \frac{0.529P\,(1+0.54\mu)}{h^2}\left[4\log_{10}\left(\frac{l}{b}\right) + \log_{10}(b) - 0.4048\right] \qquad (2)$$

The interior loading stress (i) in the slab shown in equation 3.

$$\sigma_i = \frac{0.275P\,(1-\mu)}{h^2}\left[\left[4\log_{10}\left(\frac{l}{b}\right)\right] + \log_{10}\{12(1-\mu^2)\} - 0.436\right] \qquad (3)$$

Where: P = wheel load (N), h = thickness of slab (mm), l = radius of relative stiffness, b = radius of equivalent distribution of pressure at the bottom of the slab (mm). The value is calculated from the Equation 1, 2 and 3

b=$\sqrt{1.6a^2 + h^2} - o.675h$ for a< 1.724h

b=a for 1.724h≤a,

The data used for calculating wheel load stresses is shown in Table 1.

Table 1: Pavement Data for Wheel Load Stress Evaluation

Wheel load, P(kg) (IRC1988-58)	Radius, a(cm)	Pavement Thickness, h(cm)(Assumed)	Modulus of Sub Grade Reaction, k (kg/cm^3)(Assumed)	Modulus of Elasticity of Concrete, E	Relative Stiffness l,(cm)	Equivalent Radius, b(cm)
5100	15	15	3	$3x10^5$	73.23	14.06
5100	15	20	3	$3x10^5$	90.87	14.06

Using the data of Table 1 in equations 1, 2 and 3, the following results are obtained that are presented in Table 2.

Table 2: Wheel Load Stress Results

stress at corner σ_c (kg/cm^2)	stress at edge σ_e (kg/cm^2)	stress at interior σ_i (kg/cm^2)
52.63	51.60	50.53
31.57	29.03	14.75

The results indicate that maximum traffic stresses occur at corner in concrete in which defection is higher causing early breakage at the corners, which is mainly due to pavement concrete thickness.

WARPING STRESS

Westergaard considered the rigid pavement slab as a dense liquid resting on a soil-sub grade. The relative stiffness of the slab and sub grade is defined as in Equation as follows (Westergaard1933):

$$l = \sqrt[4]{\frac{Eh^3}{12(1-\mu^2)k}} \qquad (4)$$

Where: l = radius of relative stiffness (m), E = modulus elasticity of the pavement (Pa),h = thickness of the pavement (m), μ=Poisson's ratio of the concrete pavement (μ=0.15), k= modulus of sub grade reaction (kg/cm^3).

Westergaard has also developed equations for warping stresses which were later modified by Brad bury, both equations for corner and edge warping stress are given below

$$\sigma_c = \frac{E\alpha t}{3(1-\mu^2)}\sqrt{\frac{a}{l}} \qquad (5)$$

$$\sigma_e = \frac{1}{2}E\alpha t C_x \qquad (6)$$

$$\sigma_e = \frac{1}{2} E\alpha t C_y \quad (7)$$

Note: higher value of C_x/C_y is taken for calculation purpose.

Where the coefficients C_x and C_y developed by Bradbury which depend on the slab length l_x and l_y.

Table 3: Pavement Data Used For Calculation of Warping Stress

Slab Thickness, cm	Temperature Differential(℃) in Slab Region (IRC 1988-58)
15	17.3
20	19.0

Source: Text book of Justo and khanna page number 395

Table 4: Warping Stress Results

l (Relative Stiffness)	L_x/l	L_y/l	C_x	C_y	σ_e(kg/cm^2)	σ_c(kg/cm^2)	Edge Load Stress s_e(kg/cm^2)	Corner Load Stress s_c(kg/cm^2)	$\sigma_e + s_e$	$\sigma_c + s_c$
57.31	8.72	6.10	1.02	0.95	26.46	10.41	44	48	70.46	58.41
71.11	7.03	4.92	0.98	0.72	25.43	10.26	22	30	53.43	40.26

From the critical combination of the stress we know that stress depend on radius of relative stiffness and sub grade condition and the result indicate that the stress at the edge is higher than corner stress.

COMBINATION OF VEHICULAR LOAD AND WARPING STRESS

The stress and deformation developed in the pavement are generally influenced by the position and thickness of the pavement as the deformation of the slab depends on the supporting material and modulus of sub-grade reaction (k). According to the Westergaard equations, the maximum stress were mainly caused by wheel load stress especially corner loading stresses which were far beyond the flexural stress and maximum stress caused in warping is due to edge stress.

Table 5: Stresses in the Pavements

Wheel Load Stress	Value kg/cm^2	Warping Stress	Value kg/cm^2
σ_c	52.63, 31.57	σ_c	58.41, 40.26
σ_e	51.60, 29.03	σ_e	70.46, 53.43
σ_i	50.53, 14.75	σ_i	Not calculated

From the above table warping stress in corner region (σ_c) is higher as compared to the wheel load stress. The stress at edge (σ_e) is much higher for warping stress as compared to the wheel load stress.

CONCLUSIONS

Comparative study of concrete pavement for wheel load stress and warping stress shows that the stresses in the concrete pavement are caused by sub grade condition, pavement size, and moving loads. The warping stress results were more significant than traffic load stress. The Effects of warping stress are equal in importance to wheel load stress and considered for better pavement design. Concrete slab is generally considered to be most critical and for the concrete

pavement design the responses of these two stresses must be considered which cause the deflection and cracks in the concrete slab.

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